Audio Alchemy

CHRIS FRANKLAND INVESTIGATES THE MYSTERIOUS WORLD OF THE STEP-UP DEVICE, LISTENING TO A SELECTION OF M-C TRANSFORMERS AND TALKING TO LEADING DESIGNERS

'With a transformer it's easier to design a low-noise, moderately high input impedance, moderately high sensitivity amplifier."

When it comes to 'stepping up' the minimal output from a moving coil phono cartridge to line level, the most common modern solution is an active 'pre-pre-amp'. But there is another way: in the days of valve amplifiers, stepping up the low output from a moving-coil cartridge could only be done with a transformer.

Modern transistors and op-amps might offer much better signal-to-noise ratios, so are used in many modern pickup cartridge amplifiers. But some reckon that there is no substitute for doing things the old way, with a transformer rather than an amplified gain stage. Why?

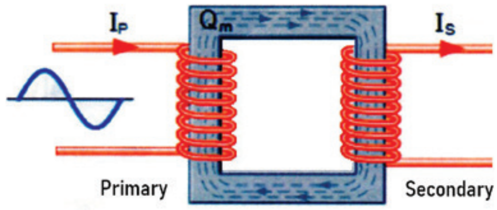
Andrew Rothwell reckons that the reason is simple: "A good transformer gives the best performance from a moving-coil cartridge." He explains that the distortion produced in transformers is greatest at lower frequencies, and falls rapidly as frequencies rise, whereas in transistor amplifiers harmonic distortion tends to rise with frequency and intermodulation distortion tends to be higher than a transformer. A similar point is also made by Ortofon in its *ST7* transformer manual.

Although he says that step-up transformers are "the most esoteric and misunderstood items in the world of hi-fi", Rothwell notes that "transformer distortion is aurally very benign compared with that produced in transistor amps" which he believes explains why "the sound produced when a moving-coil cartridge is used with a good transformer is so sublime". However, he also points out that transistor technology is inexpensive, whereas the materials used in transformers are much more costly.

As an example, Audio Note's sublime *S9* model is a sobering £16,500, but then look at Martin Colloms' lab results for the *S9* (*HIFICRITIC Vol4 No3*) and you will see that distortion measured a minuscule 0.00045% at 1kHz, and fell with reducing input level until it was 'lost in instrument noise'.

Few companies have as many transformers in its product range than Audio Note UK. Founder Peter Qvortrup once told me that metallurgy is at the heart of everything they make, and that's never more true than in transformers, where the choices made for the core laminations and windings are super-critical.

For example, talking about the materials used for core laminations, Audio Note chief designer Andy Grove says that the company uses iron alloyed with costly nickel. But he points out that you can't simply keep increasing the nickel percentage and expect performance to continue to improve: due to the internal crystalline structure, losses in quality can occur at certain ratios where performance becomes suboptimal.



In essence a transformer comprises two coils of wire that are linked by a common magnetic circuit, in the form of a central ferromagnetic core. The input signal flows in the primary winding and a corresponding signal is induced in the secondary coil; if the number of turns on the secondary is greater than in the primary, the output voltage will be greater than the input. (This is the principle of a step-up transformer. It can take the low impedance, low voltage signal from a moving-coil cartridge and step it up to a higher voltage for a pre-amp input.)

And although apparently simple in operation, for the best sound a kind of magic is at work, and transformer design has long been regarded as a black art, as Grove has already intimated.

Alchemy (of a Sort)

So what are the advantages of using a transformer rather than an amplified gain stage? In the opinion of Terry Bateman (electronics designer at Rega): "Designing a low-noise pre-amplifier with high input sensitivity and the low input impedance required by an moving-coil cartridge is not an easy task. Using a transformer, which in a quirky sort of way can be seen as organic 'gain', makes it simpler.

"With a transformer it's easier to design a low-noise, moderately high input impedance, moderately high sensitivity amplifier." As Rega showed in its *Ios* phono stage, which used a Sowter *8055-F* transformer.

CHRIS FRANKLAND

Bateman expands that: "Considering the impedances encountered in moving-coil amplifiers and the desire to avoid a coupling capacitor between the input of the amplifier and the cartridge, the transformer can been seen as an interface to buffer the cartridge to the amplifier input. Even if the input of the pre-amplifier is referenced to earth, and the cartridge is connected directly to the input with, say, a 100ohm load resistor, a minuscule amount of bias current will still be flowing into the coil of the cartridge, which appears to upset it. This would be blocked when using a transformer."

For his latest phono stage (Rega *Aura*), however, Bateman selected an FET for the input: "FETs have no bias current to speak of, so the cartridge can be connected to the amplifier without using a coupling capacitor. By using ultra-low-noise FETs it's feasible to design a high-gain, low-noise pre-amplifier without a transformer, and avoiding the coupling capacitor."

Andy Grove puts it this way: "[In a head amp] you're loading the cartridge with a simple resistor, not a complex impedance. You will never get the low noise performance of a transformer with a head amp because a transformer is translating the power it gets, rather than amplifying it."

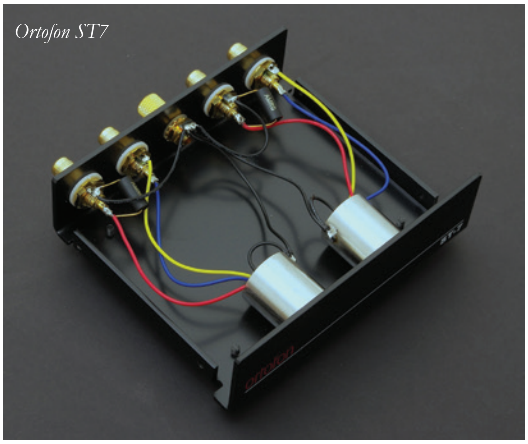
But using transformers is not all plain sailing, as there's still the thorny issue of impedance matching with the cartridge. Andrew Rothwell points out that as a general rule, you need to feed the signal into a load at least 10X greater than the source impedance to avoid significant signal power loss. Most modern moving-coil cartridges have a source impedance of around 10ohms, and a good rule of thumb is that they will like to look at an impedance of around 100ohms.

For my test, this presented certain problems, as the AN *Io* cartridge, although ideally matched with the AN transformers, would not necessarily be happy with alternatives. Its very low output of 0.05mV compares with a more typical average of 0.2 - 0.5mV. The AN transformers (£993 *S2*, £4,767 *S4*, £6,754 *S5*, £10,115 *S8* and £16,576 *S9*), are of course matched to this output, but the Ortofon *ST7* and Puresound *T10* are not, so I also used an Audio Technica *OC9 III* cartridge. (However, it's worth noting that Audio Note will custom-match a transformer to order for a customer's chosen cartridge.)

Sound Quality

The transformers at lower prices include the Ortofon *ST7* (£450), the Puresound *T10* (£339) and the Audio Note *S2* (£993), which were compared to a Rothwell *Headspace* head amp (£375).

The Ortofon *ST7* is described as using high-quality 'sandwich wiring', which Ortofon says



Ortofon ST7

significantly improves high-frequency performance, while Permalloy shielding is used to reduce hum pickup. Gain is quoted as 24dB and it is said to match cartridges with impedances from 2 to 60ohms. Although it seemed to handle both the Audio Note *Io* and the Audio-Technica *OC9* well enough, most of the listening was done with the *OC9*. I felt the *ST7* made vocals more open, conveyed note shape on guitars better, was more convincing and coherent on electric and acoustic basses than the Rothwell *Headspace*, and maintained a sense of pace and dynamics.

The Puresound *T10* uses 80% mu-metal cores custom made for Puresound; with copper coil windings. Puresound's Guy Sergeant is also of the view that you can't really control an moving-coil cartridge's generator coil with a load resistor, and will run into difficulties trying to make an active stage quiet enough to retrieve and amplify such tiny signals.

How did the *T10* compare with the slightly pricier Ortofon? It only took a short blast of Free's

Andy Grove of Audio Note

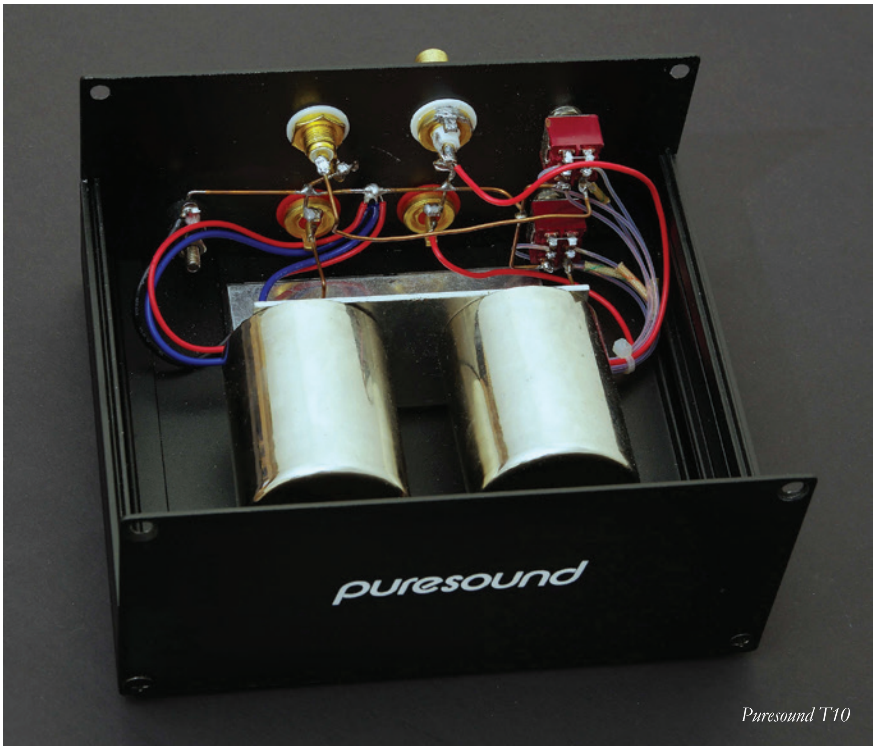
Broad Daylight to convince me that although the *ST7* was good, *via* the *T10* I could hear more detail in percussion, bass lines were deeper and better controlled, and piano and vocals more open and better defined.

A quick listen to John Mellencamp merely confirmed those initial views: the *T10* had more bite on guitar and vocals, and the track definitely rocked along better, so the *T10* had the edge and is also £100 less costly. (Sergeant also sent me his gorgeous *P10* valve phono stage, which sounded like a cracker on first acquaintance!)

Comparing the various Audio Note transformers gives a unique insight into the sonic contributions of the coil winding material, how the coils are wound, the size of the former used, and the material used in the core laminations, all of which may have a significant effect on performance.

The *S2* has the smallest former with copper windings and a simple 80% nickel mu-metal core. The *S3* (not tested) and *S4* use Super Mumetal cores, but where the *S3* has copper coils, the *S4* is the first of the range to use silver of 99.99% purity. The *S5* and *S8* have bigger formers and a larger Super Mumetal core, only differing in that the *S5* has copper windings and the *S8* uses silver. The *S9* has a much larger former and a slightly higher grade of silver wire.

Comparing the *S5* and the *S8* should reveal the difference between copper and silver windings, but as a baseline, how much better is the £990 Audio Note *S2* than the Puresound and Ortofon at half its price? A few bars of Mellencamp's *Hurts So Good* soon convinced me that the *S2* had more bite on guitars, more detail, greater delicacy and attack on drums, and helped the track to rock along better. On balance it was more detailed, articulate and dynamic, making it well worth the extra money.



Puresound T10

So can the AN *S4* with its silver coil windings really be worth £4,700? Well, I have to say that it provided a substantial advance in quality. Vocals were more natural and articulate, drums and percussion were cleaner and more dynamic, bass guitar lines were tighter, deeper and more rhythmic, and the sound was more detailed overall with a better layering of detail and nuances.

I was particularly interested to compare the *S5* with the *S8*, as the only difference here is that the more costly model has silver coil windings. Would it really make a difference? Eric Clapton's *Lay Down Sally* helped me decide, as drums were snappier and more coherent, voices had more presence and character, and backing vocals were much better separated. Bass lines were tighter and more rhythmic and the whole sound was much more detailed. Would I pay extra? I would; once heard, it's a no-brainer.

'Exceptional' is how Martin Colloms described Audio Note's top-of-the-line *AN-S9* transformer, but my overall summary would be 'sublime'. The *S9* is a whopper of a transformer, the largest formers in the range, and this apparently gives more scope to reduce capacitance. Also, Audio Note hard-wired a special silver palladium cable directly to the transformer secondaries.

Because of this transformer's high gain, there's a chance that hum and RF pickup could be an issue; Audio Note advises siting caution, but I never had any trouble. Colloms described how the S9 'knocked spots off' the *S4* he'd been using, so is it worth the extra £6.5k over the *S8*? The answer is a resounding 'yes'. On Joe Cocker's *Seven Days* the drumming and percussion were better layered and separated while the bass line was tighter and more rhythmic, with beautiful detailing and plenty of drive and dynamics. Ben Sidran's piano and vocals were conveyed superbly, and bass lines were tight, coherent and snappy. Time and time again the *S9* delighted and surprised. It's a formidable performer and ought to be tried if the ultimate in transformers is sought.

Conclusions

We now have an insight into what makes moving-coil step-up transformers tick, and have seen and heard proof positive that the materials used in construction have a critical bearing on sound quality. Choose your budget and take your pick!

ANDY GROVE OF AUDIO NOTE DISCUSSES MOVING-COIL TRANSFORMER DESIGN

Q: How does a transformer work?

The signal voltage across the primary causes a current to flow in that winding, creating a magnetic field in the core that is proportional to fixed parameters, such as core geometry, and follows the signal voltage. The magnetic field strength is the same for a given core cross-sectional area and the number of turns, but the amount of current is less with a higher permeability core.

The core itself is taking less from the primary circuit when the core material permeability is high, which is why we use an efficient alloy like mu-metal.

As the primary and secondary share a common core, and the magnetic field is common to both, the secondary voltage will be in proportion to the ratio of turns multiplied by the primary voltage. That's how the voltage step-up or gain is achieved. It's not power gain in the same way as an amplifier provides. It's more like taking a bucket of water and filling 100 cups with that same water, whereas a head amp measures the volume of the bucket, throws the water away, and takes water from somewhere else (the power supply) to fill the cups.

Q: How do transformers stack up against head amps?

If you're looking at the low output of 30μV from an *Io Limited* and 50μV for the *Io*, and a load of 2-3ohms, with a source impedance of about 1ohm, it's difficult to find any kind of active device that will not produce more noise [than a transformer], even when using very low-noise bipolar transistors. The voltage gain of a transformer is essentially noiseless. because it's an impedance transformation (though in fact there's some magnetic contribution from the transduction, such as Barkhausen noise.)

If you go into the pro sector, with its dynamic and ribbon microphones, a transformer is often found. A moving-coil cartridge has coils wound on a yoke which moves in a magnetic field, with an associated inductance, and an impedance characteristic that results from all the different parts of that magnetic circuit.

A transformer primary is complementary, so you're loading the cartridge with something that is similar to its own nature, rather than just loading it with a resistor for an active head-amp, and then adding as much gain as you can.

Q: Could you gain an advantage for a head amp by offering a range of input impedances?

It's nice to think you can buy a head amp and use a wide range of cartridges with it, but you are inevitably going to run into problems with gain and noise unless you stay with cartridges in the range for which the amp was designed.

Regarding load impedance, again, it's a maybe and depends on many factors. With a transformer, the case is clearer. It's better to have a transformer for the job, or at least one that is designed for a close match.

Q: Impedance-wise, how critical is it to get the transformer matched to the cartridge?

There is a bit of leeway, we normally think about a transformer with three to five times the cartridge impedance, when the transformer output is loaded by the usual 47kohms. We do make transformers for other cartridges, bespoke units, but the best ones are matched to our cartridges.

Q: So what is it within the transformers themselves that makes the substantial differences I've been hearing?

There are three factors. First, the core material and construction: eddy currents flow through a solid core, but laminations can control that, as there is insulation between the laminations. The laminations are electrically insulated from each other, so the induced current can only flow along a limited path. The core alloy can also be chosen for a higher resistance.

With the nickel-iron alloys, a mix of about 50% has the highest saturation flux (power per unit volume), while about. 80% nickel (the mu-metal permalloys) have the highest permeability or magnetic product and also lowest magnetostriction,. A modest 55% nickel-iron mix actually has quite poor magnetic properties unless it is heat-treated.

Q: So you can't just keep on making the percentage of nickel greater and it'll be better?

No; this is due to the crystalline structure. As you go from pure iron at one end to pure nickel at the other, invoking the alloy phase diagram, certain electromagnetic properties peak out. Saturation flux is one, permeability and magnetostriction are others, as is electrical/DC resistance.

There are dips with alloy ratios where the properties could be seen as suboptimal. However, if a 55% alloy is heat-treated correctly it can give performance gains that combine the advantages of Mumetal (80%) and Radiometal (50%).

For our best moving-coil transformers, and those used in the *M9* RIAA, we have started to use Carpenter *HyMu 800*, with a special bespoke heat treatment from a manufacturer who is receptive to the quirkiness of audio specifications.

Q: From cheapest to most expensive, how do AN transformers progress in terms of material choices?

The base material will always be quite similar, but the lamination thickness will differ. Again, with regard to eddy currents, the thinner you make the laminations the better. We use overlapped E and I cores in the moving-coil transformers. There will always be eddy current paths, and the thinner you make the laminations, the lower the losses will be, while permeability goes up, improving the low frequencies (Laminations have an isolating magnesium oxide dust coating, which insulates them.)

Core specifications for all of the range will be similar. The *S9* has a massive core and a lot of space on the bobbin, so you can put the insulation where you want it. The smaller cores are a bit of a pain to make, as one doesn't have the flexibility.

The silver wire used for the *S8* is largely the same as that used in the *S9*. A lot of what you hear and see is the result of the fact that it's larger. As American hot-rodders put it: "there ain't no substitute for cubes".